Electrostatic Analyzer for 1.5-Mev Protons

W. A. Fowler, C. C. Lauritsen, and T. Lauritsen
Kellogg Radiation Laboratory, California Institute of Technology, Pasadena, California
(Received July 14, 1947)

A system for analyzing the ion beam of an electrostatic generator is described. A weak magnetic field separates protons from heavier components and a 90° electrostatic deflection gives the required energy resolution. With the analyzer controlling the generator voltage, a proton beam of one microampere with an energy spread of the order of 300 volts in one million is obtained.

In recent work on the study of reasonance levels observed in proton and deuteron bombardment of light nuclei, more and more emphasis has attached to the problem of obtaining bombarding particles homogeneous in energy to an accuracy of the order of a few hundred volts in a million. Although the Van de Graaff electrostatic generator provides a voltage which is constant to this order of accuracy over short periods, it is necessary to provide external stabilization for runs of any practical length. In addition, since the ion-accelerating tube produces particles of several masses, each with some spread in energy, it is necessary to reject from the beam particles of other than the desired mass and energy. These ends are ordinarily accomplished by magnetic or electrostatic analysis of the beam, and by allowing the deflected beam to control the generator voltage.[1-3]

In order to effect complete separation of a proton beam it is necessary to use both magnetic and electrostatic analysis, since singly-charged particles of double mass and half-energy would undergo the same deflection in a magnetic field as full energy, single mass particles, and an electrostatic field makes no distinction between different masses for a given energy. Since deuterons are always present, at least in proportion to the deuterium content of the hydrogen supplied to the ion source, the ambiguity of a single deflection can be quite inconvenient when weak proton reactions are to be studied. If the magnetic and electrostatic deflections are mutually perpendicular, only one needs have a high resolution, the other serving merely to reject components at half-energy or at double mass. The particular arrangement described in this paper utilizes a coarse magnetic separation followed by a high resolution electrostatic analysis, primarily because the precision measurement and control of the analyzing field is somewhat easier than would be the case if the main deflection were magnetic.

The main features of the analyzer are shown schematically in Fig. 1, and a photograph of the arrangement is reproduced in Fig. 2. The deflecting plates comprise two $2\frac{1}{2}$-inch$\times\frac{1}{4}$-inch brass strips curved through 90° on a 1.1-m radius and separated by 8.6 mm. They are supported on 8 Microy insulators equally spaced along the arc, and the whole assembly is enclosed in a 4-inch brass pipe bent to the same radius. The strips were adjusted by bending and shimming to constant spacing within about 0.005″ and to constant curvature to 0.015″. The upper end of the analyzer is attached to the accelerating tube by means of a short length of 2-inch pipe and a sylphon bellows. Rough separation of the beam into its component masses is accomplished by a relatively weak magnetic field just below the bellows. For this purpose the beam is defined by an aperture immediately above the magnet ("*a*" in Fig. 1) and by a slit, "*b*," about 50 cm below the magnet, offset about 2° from the line of the undeflected beam. Aperture "*a*" is actually a 3-mm hole in a tantalum disk which can be rotated about a diameter perpendicular to the electrostatic field, so that its width parallel to the field is adjustable. In the vertical position the disk appears as a hairline in the focal spot and is so used for preliminary alignment. Slit "*b*" can be replaced with a quartz disk for visual focusing.

For electrostatic deflection the beam is defined

[1] Bennett, Bonner, Mandeville, and Watt, Phys. Rev. **70**, 882 (1946).
[2] A. O. Hansen, Rev. Sci. Inst. **15**, 57 (1944).
[3] Bender, Shoemaker, and Powell, Phys. Rev. **71**, 905 (1947).

by aperture "a" and slits "c" and "d." Aperture "a" is adjustable, as indicated above, and is ordinarily used at an effective width of 0.5 to 1.0 mm. Slit "c" can also be adjusted in width, but again is fixed as to center. Slit "d" is fixed at an opening of about 0.7 mm. A movable quartz disk can be interposed in front of this slit for alignment. The undeflected beam can be checked by swinging out a section of the outer deflector plate and observing the spot on a quartz target at the bottom of the vertical tube ("e," Fig. 1).

The entire assembly is hung from a bifilar suspension, permitting translation with respect to the accelerating tube to align the focal spot. Angular adjustment is accomplished by means of turnbuckles in the suspension but is very rarely required. As might be expected, this adjustment was quite critical in the initial lining-up in order to make possible the use of the full aperture of the deflecting plates, but is not affected by small motions of the focal spot.

The deflecting potential is supplied by a double-ended transformer rectifier set capable of delivering up to 20 kv each side of ground. The circuit used for stabilizing this voltage is shown in Fig. 3. Essentially the circuit operates by changing the impedance of transformer T-1 in series with the high voltage transformer, the changes being

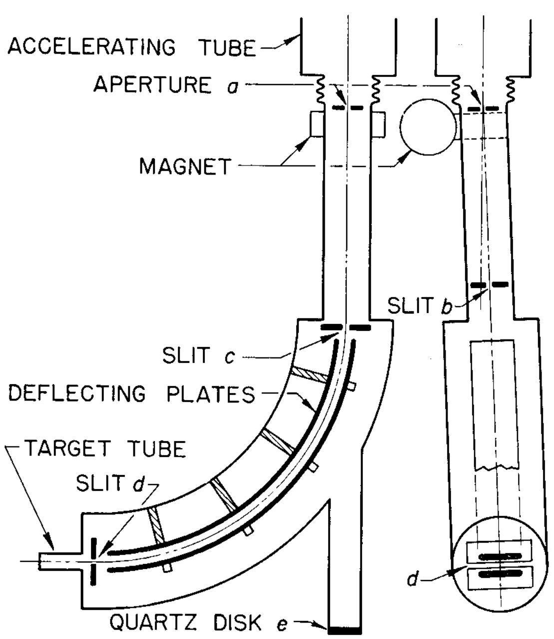

FIG. 1. Schematic diagram of electrostatic analyzer.

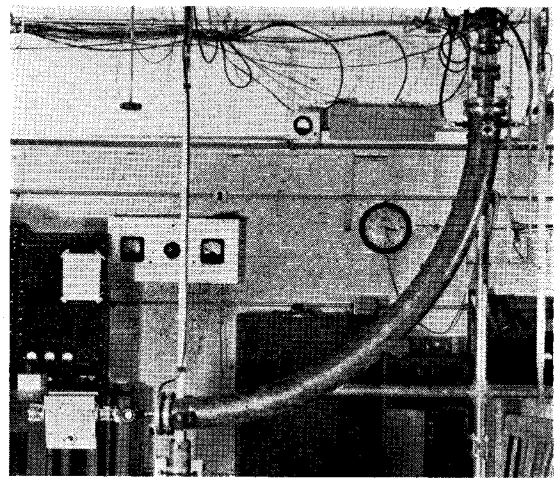

FIG. 2. Photograph of analyzer and suspension system.

determined by the drop in a fraction of a 40-megohm resistor across the high voltage output which is compared with an adjustable standard voltage supplied by a battery. The magnitude of the deflecting voltage is read by means of an independent, thermostated 120-megohm resistor column and a Leeds and Northrup Type-K potentiometer. The beam energy is, of course, directly proportional to this voltage, and this measurement is used to determine the generator voltage. The system is quite stable and holds a set voltage within a few hundredths of one percent for many minutes. For longer runs the slow drifts are easily compensated manually.

One difficulty which can be rather serious and which places severe restrictions on the usable divergence of the proton beam is the secondary emission occasioned by particles striking the deflector plates. Poor vacuum, or slight malalignments, can easily result in current drains, particularly from the negative (upper) plate, of 50 to 100 microamperes, completely destroying the stability of the system. In fact, under these conditions the beam will often "lock" against the upper plate and vary the deflector voltage with the generator voltage, giving a stationary spot of undetermined energy. With proper adjustment and a sufficiently narrow beam the current to the deflector plates is less than 1 microampere with a beam current of 1 microampere.

The generator voltage is controlled by the beam by the use of a variable corona load, in the

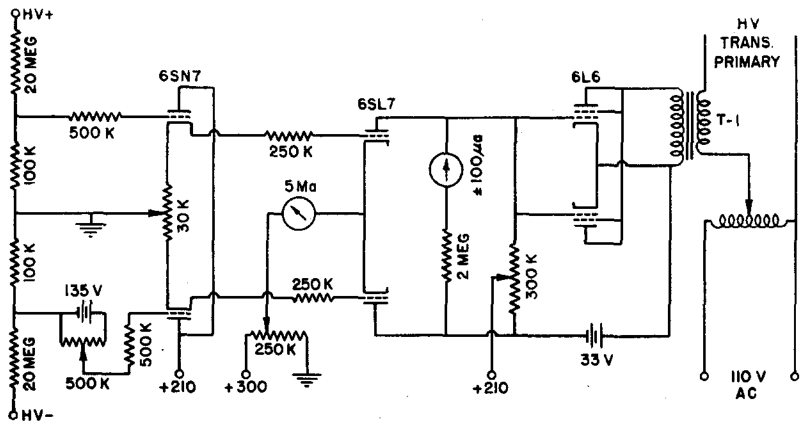

FIG. 3. Voltage regulator circuit. (Rating of transformer T-1: 900-volt secondary, 15-ma sec., 115-volt primary.)

manner described by Ashley and Hansen.[4] The two jaws of slit "d" (Fig. 1) are insulated from one another and from ground. If the beam leaves the center position and strikes either slit jaw the resulting current is amplified and made to control the bias on a set of five guarded corona needles facing the high voltage terminal electrode of the generator. The distance of these needles from the terminal can be varied and is set so that a current of 20 to 40 microamperes is drawn with a bias of 2500 volts. Variation of the bias from the median value to 0 or to 5000 volts doubles this load or reduces it to zero, giving adequate control for most fluctuations. Although no effort has been made to include the ultimate refinements in the stabilizing circuits, the voltage as indicated by a generating voltmeter and as observed by the location of the analyzed beam can be held constant to a few hundred volts for long periods of time.

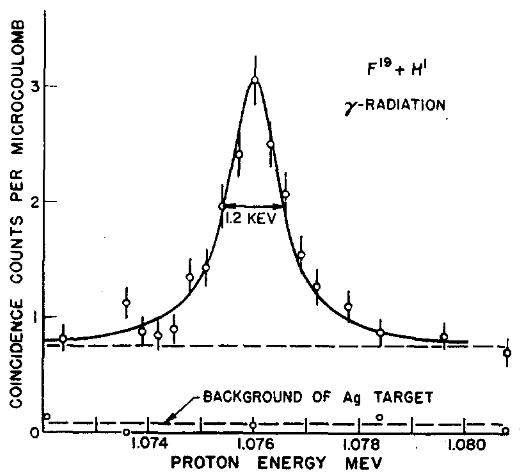

FIG. 4. Excitation curve obtained with analyzer system.

[4] R. M. Ashley and A. O. Hansen, Rev. Sci. Inst. 13, 128 (1942).

As a test of the resolution obtainable with the entire system, the resonance at 1070 kev in γ-ray emission from fluorine bombarded by protons was studied with some care (Fig. 4). This resonance was reported by Bennett, Bonner, Mandeville, and Watt[1] and was estimated by them to have a real width of less than 1.9 kev. Our results substantiate this conclusion, indicating even a somewhat smaller upper limit for the width, and show that reproducible settings can be made at intervals of the order of 300 volts.

We are particularly indebted to J. W. Williams, J. L. McKibben, A. O. Hansen, and C. M. Turner for much helpful advice, and for supplying details of their control equipment. Acknowledgment should also be made of the valuable assistance of Mr. L. Gililland and Mr. G. Fastle in solving the many mechanical problems of constructing the analyzer and of Mr. W. D. Gibbs who assisted in the design and construction of the electronic circuits.

This work was carried on under contract with the Office of Naval Research.